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ISSN 0193-3728

Methods of Applying Carbon Dioxide for Insect Control in Stored Grain

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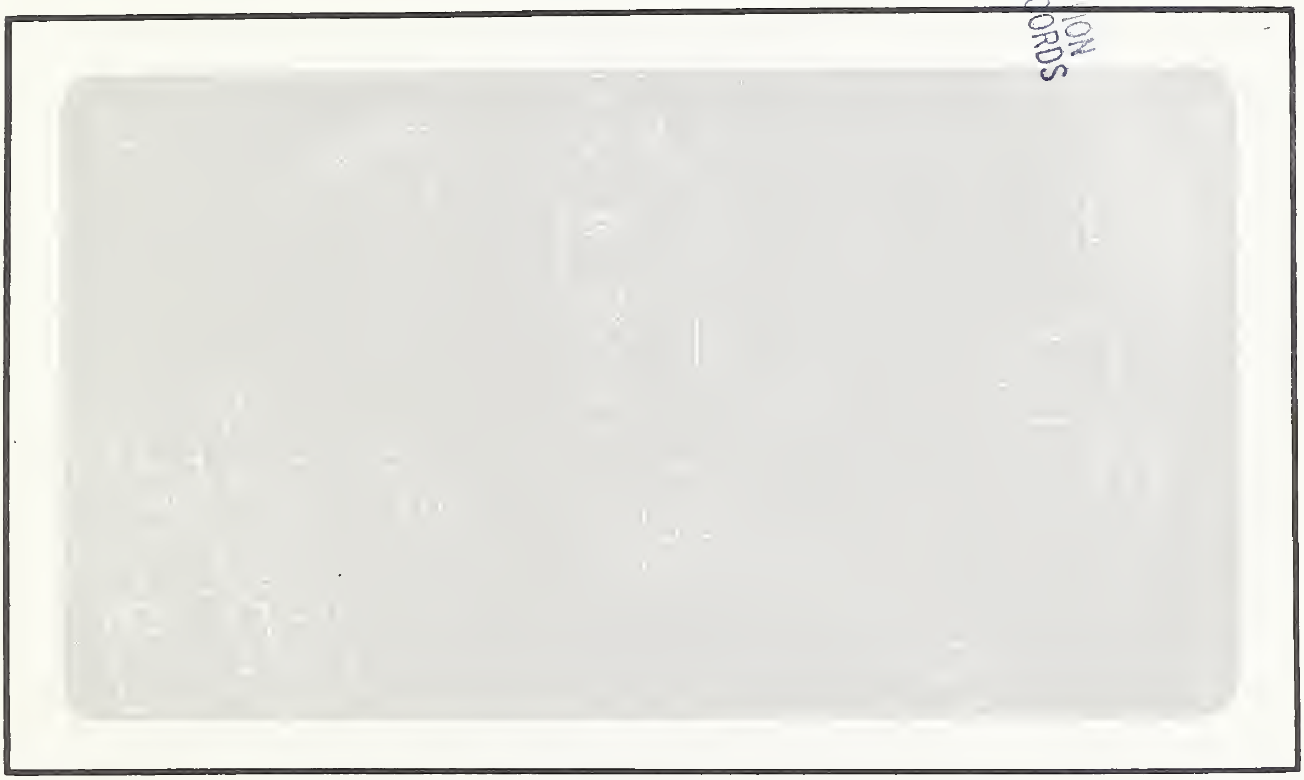

U.S. Department of Agriculture
Science and Education Administration
Advances in Agricultural Technology • AAT-S-13/April 1980

The success of these tests is partially due to the efforts of G. C. Pearman, Jr., of the Stored-Product Insects Research and Development Laboratory. The Farm Bureau Marketing Association's terminal elevator. North Charleston. S.C.. furnished the facility and grain. Liquid Carbonic Corp., Chicago, Ill., provided a portion of the CO_2, and Art Riechert of this company furnished engineering expertise.

This publication is available from the Stored-Product Insects Research and Development Laboratory, P.O. Box 22909, Savannah, Ga. 31403.

Science and Education Administration, Advances in Agricultural Technology, Southern Series, No. 13, April 1980.

Published by Agricultural Research (Southern Region), Science and Education Administration, U.S. Department of Agriculture, P.O. Box 53326, New Orleans, La. 70153.

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Methods of Applying Carbon Dioxide for Insect Control in Stored Grain

By Edward Jay[1]

ABSTRACT

Three methods of applying carbon dioxide to grain stored in silos are described. One method involves purging a full silo from the top, another involves purging a full silo from the bottom, and the third involves introducing carbon dioxide in the grain stream as a silo is being filled. Comparative purge times, carbon dioxide requirements, and costs are given. Modification of storage-facility atmospheres is a promising method to achieve residue-free insect control, and the merits of using carbon dioxide and nitrogen for this purpose are compared. Index terms: carbon dioxide, insect control, modified atmospheres, nitrogen, stored-product insects.

INTRODUCTION

Since the publication by Jay (1971) on using carbon dioxide (CO_2) to control stored-grain insects, considerable interest has developed worldwide on the use of this technique and on the use of nitrogen (N_2) and on combinations of atmospheric gases to achieve control. This interest has been generated because of the increasing worldwide problem of insect resistance to conventional insecticides and fumigants and also because of the residues associated with the use of these materials. Jay and Pearman (1973) showed that a 4-day CO_2 treatment of shelled corn having a natural infestation of stored-grain insects gave almost 100% control. Shejbal et al. (1973) showed that similar control could be obtained by using N_2, but the time needed to obtain control was 10 days. Banks and Annis (1977) conducted trials with N_2 in commercial, upright, welded-steel silos. Lethal atmospheres were attained and maintained in these silos for periods up to 30 days.

Both CO_2 and N_2 have merit in a residue-free insect-control program. Nitrogen has the advantage of filling 78% of the interstitial spaces initially. However, atmospheric oxygen (O_2) in these interstitial spaces must be reduced to less than 1% to obtain effective insect control, a situation difficult to achieve and maintain in storage facilities that are not gastight. Therefore, CO_2 is considered by the author to be more efficient than N_2 in situations where tight sealing is physically impossible or where it is not economically feasible to seal the storage structure to rigid gastight specifications. A CO_2 concentration of about 60% will give over 95% control of most stored-grain insects after a 4-day exposure at temperatures of 27° C or higher (Jay 1971), and the CO_2 concentration can fluctuate ±10% and still provide effective control. The low-oxygen N_2 atmosphere, on the other hand, must be held for 10 or more days at 27° C or above to be effective against life stages of stored-grain pests. Even so, Shejbal et al. (1973) reported that control of insect eggs was not obtained in a 10-day exposure to 0.5% O_2 and 99.5% N_2. Unpublished laboratory

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studies by the author have shown that eggs of the red flour beetle, *Tribolium castaneum* (Herbst), do not hatch in atmospheres above 20% CO_2 when the O_2 level is as high as about 19%. Similarly, AliNiazee and Lindgren (1970) reported that the percentage of egg hatch of *T. castaneum* and *T. confusum* Jacquelin duVal was inhibited partially or completely delayed in CO_2 atmospheres, while in similar N_2 atmospheres there was about the same percentage of egg hatch as there was in those eggs exposed to air. The author (unpublished laboratory studies) found that a concentration of about 62% CO_2 and 9% O_2 gave over 90% control of 0- to 25-hour-old eggs of the cowpea weevil, *Callosobruchus maculatus* (F.), in 2 days' exposure, while concentrations of 99.2% N_2 (balance O_2) took 3 days to produce the same results. One-week-old insects of the same species were controlled (90% or more mortality) in 2 days in the atmosphere containing 62% CO_2, while concentrations of 99.7% N_2 (balance O_2) took more than 3 days to give the same control.

In summary, CO_2 generally kills insects faster than N_2. It can be used in situations where leakiness may be a problem, and the concentration of 60% CO_2 can be allowed to fluctuate ±10% (or more, down to a low of 35%) leading to good control. (However, lower overall concentrations will necessitate longer exposure times.) In addition, sorption of CO_2 by grain or oilseeds may make it more effective against species whose immature stages feed inside the kernel. On the other hand, CO_2 is 1½ times as heavy as air and will sink from the top to the bottom of the treated storage facility unless it is tightly sealed. This sinking necessitates either adding CO_2 into the headspace periodically or recirculating the CO_2. (See Jay et al., 1970, for a description of this method. The method should be modified so that the recirculation fan is placed outside the storage facility to eliminate explosion hazard.)

If the above advantages and disadvantages of using CO_2 have been taken into consideration and there still remains a question of whether to use CO_2 or N_2, then economic factors enter into the decision. The comparative cost of the two treatments will depend on the availability of the gases, their unit cost (a unit is a ton, pound, cubic foot, cubic meter, etc.), the number of units required for effective insect control, the amount of grain to be treated per year (as the volume of gas used increases, unit costs will be reduced), transportation costs, and rental or purchase costs of vaporization equipment and storage containers (if equipment is purchased, can it be depreciated annually?).

The above advantages, disadvantages, and economic considerations obviously involve a decisionmaking process for which a flow chart is presented in figure 1.

This paper presents three methods of applying CO_2 to stored grain. The information presented by Jay (1971) on suggested conditions for using CO_2 should be consulted in conjunction with the material presented here. If a decision is made to use N_2 instead, Banks and Annis (1977) should be studied. However, some techniques described for CO_2 could be used for N_2 with slight modifications. Another method of creating modified atmospheres, the burning of air to reduce its oxygen content, is not considered.

METHODS OF APPLYING CO_2

Since the publication by Jay (1971) became available, the author has conducted several additional field tests. One of these was described by Jay and Pearman (1973) and is summarized here (method 1) for comparative purposes with other application methods. The three methods described attain and maintain a concentration of about 60% CO_2. The tests were conducted in 1,038-m^3 (36,644-ft^3) upright concrete silos measuring 24.7 m (81 ft), excluding depth of discharge chute, by 7.3 m (24 ft). The silos each contained about 711 metric tons (28,000 bu) of shelled corn (maize) having an 11% to 16% moisture content. (In some tests the corn was moved into a silo as the CO_2 was being applied.) The equipment used in all tests for applying the CO_2, including supply tank, vaporizers, and regulators for monitoring and controlling the concentration after the desired concentration was reached, was similar to that described by Jay and Pearman (1973). Deviations will be described in the individual tests.

Method 1: Purge a Full Silo From the Top

This is essentially the method described by Jay and Pearman (1973) and will not be dealt with at length. It involves introduction of gaseous CO_2 into the headspace above the surface of the grain.

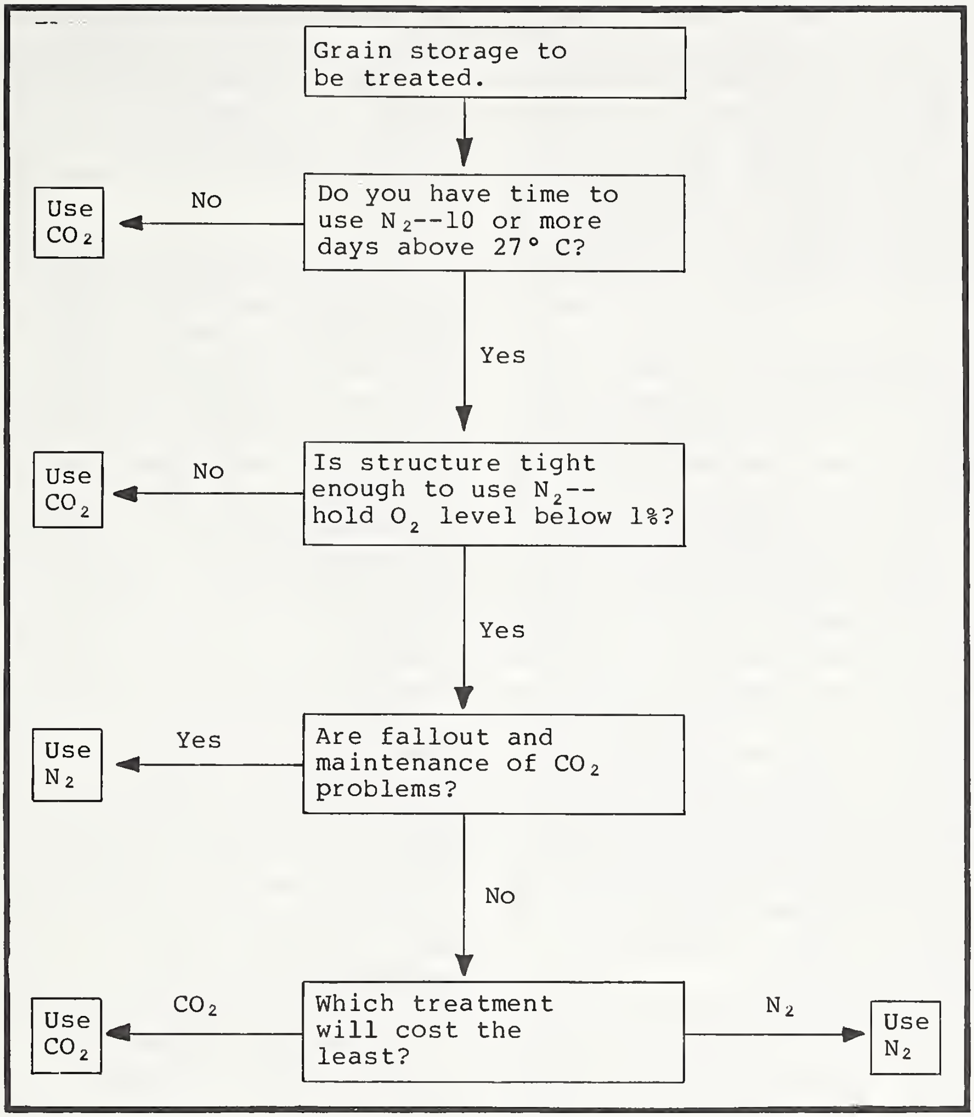

FIGURE 1.—Determining which modified atmosphere to use, CO_2 or N_2.

The CO_2 is forced down into the grain by positive pressure on the headspace of the storage facility. The CO_2 mixes with and displaces a portion of the existing atmosphere and creates a modified atmosphere lethal to any insects present. Its advantages are that it can be used where no other method is available, it requires only one application line, labor requirements are minimal, and costs may be lower than with the other methods. Its disadvantages are that CO_2 is lost in mixing and "blowback," purging time is longer than in method 3, and vaporization requirements are high.

METHOD 2: LIFT THE ATMOSPHERE OUT

In this test and in method 3, a set of air-sampling lines was placed into a silo through each of the two access openings in the flat top prior to filling. These lines differed from those which were probed into the corn in method 1. One of the two openings was about 1.2 m (4 ft) in from the wall. where the corn was discharged into the silo, and the other opening was about 1.2 m (4 ft) from the center of the top. Each set of sampling lines was made up of six 0.6-cm-i.d. (¼-inch)

polyethylene tubes taped together so that six samples could be taken at intervals of about 3 or 6 m (10 or 20 ft) below the surface of the grain. Metal tips having slits to allow air entry were placed on the end of each line. The 12 lines were run to an air-sampling valve mounted outside on the top of the silo. One line was run from this valve to a gas partitioner in a mobile laboratory. This apparatus sampled 12 sites in the silo during each test, and it was similar to that used in method 1.

Prior to filling this silo, a 0.6-m-wide (2-ft) T-shaped pipe made of 2.5-cm-i.d. (1-inch) copper tubing coupled to 1.9-cm (¾-inch) heavy-duty rubber application hose was lowered into the metal discharge cone at the bottom of the silo. The pipe had a 2.5-cm (1-inch) copper ell on each end. The ells were turned up toward the top of the silo. Fine-mesh screen was soldered over the openings to prevent entry of corn and foreign material. The silo was filled, and the depths of the sampling lines in the corn nearest the wall were determined to be about 1.2, 4.3, 7.3, 13.4, 19.5, and 25.6 m (4, 14, 24, 44, 64, and 84 ft), and near the center, about 0.6, 3.7, 6.7, 12.8, 18.9, and 25.0 m (2, 12, 22, 42, 62, and 82 ft). The difference in depth between the two sets of lines was due to the slope of the grain from the discharge area to the opposite wall. The longest side line and the center lines were in the cone-shaped discharge chute near the T-shaped application pipe.

Gas flow was started into this silo from a full 8,940-lb tank of liquid CO_2, using the built-in vaporizer. The access openings in the silo were opened after 0.6 h of application to relieve pressure. After a 1-h application, 100% CO_2 was found at the lowest (25-m) sampling points, while only small amounts were found at other sampling points. After 4 h, the CO_2 concentration at about 19 m in the center site had reached 100%, and in the side samples, from 52% to 73%.

Approximately 84 m^3 (340 lb) of CO_2 was introduced during the first 4 h of application. At this time the flow rate was increased from about 21 m^3/h (85 lb/h) to about 46 m^3/h (185 lb/h). After 6.75 h, CO_2 concentrations at the 13-m center and side sites were 95% and 20%, respectively. Samples at depths of 19 and 25 m still contained 100% CO_2 at this time. After 8.25 h of treatment, the CO_2 concentration at the 13-m side site was 89%, while samples at 7- and 4-m depths and samples just below the surface contained 2% to 4% CO_2. After 11 h, the CO_2 concentration was 95% at the 7-m center site but was only 2% at the side sampling point at this depth. Carbon dioxide used in the first 12 h was 454.4 m^3 (1,840 lb). Application was continued at an average rate of 46.0 m^3/h (185 lb/h). After 12 h, the concentration in the 7-m side site had risen to 73%.

After 13.25 h, there was 98% CO_2 at the 4-m center site, while the side sample at the same depth contained 26% CO_2. All samples below these depths contained from 97% to 100% CO_2. After 14.5 h, the sample at the 0.6-m center site had a concentration of 93% CO_2, and the sample at the 1.2-m side site contained 12% CO_2. This low concentration was probably caused by a heavy concentration of foreign material in the area. Approximately 592.7 m^3 (2,400 lb) of CO_2 had been used at this time. Flow was terminated, and it is calculated that 2 additional hours at 46.0 m^3/h (185 lb/h) would have been required to penetrate the heavy concentration of foreign material under the discharge chute at the side.

Ten hours after shutdown all samples at and below 13 m had 80% or more CO_2, while samples above this point contained from a trace to 22%. Thirty-two hours after shutdown samples at or below 19 m had 52% to 80% CO_2, and samples above this point contained from a trace to 26%.

This silo was not equipped with an aeration fan, a fan shaft, or any other facility for introducing CO_2 directly from the bottom of the silo. In silos so equipped, there would be no need for the hose and the T-shaped pipe used.

The advantages of this method are low labor requirements, CO_2 costs comparable to other application techniques, and no loss of CO_2 in mixing and blowback. On the other hand, this is the slowest of all the methods tested, and there are problems in penetrating areas having a lot of foreign material. Also, the method produces a 100% CO_2 concentration, and concentrations above 60% seem to result in reduced insect control. (Apparently, a low oxygen, O_2, concentration anesthetizes the insects and prevents the venting of CO_2 and water, which is believed to be partially responsible for death.) However, this could be averted by blending air with the CO_2, producing a concentration of about 60% CO_2 and reducing total CO_2 used. Finally, two application lines are required, one to purge and one to supplement fallout of the heavier-than-air CO_2 from the headspace, and vaporization requirements are high.

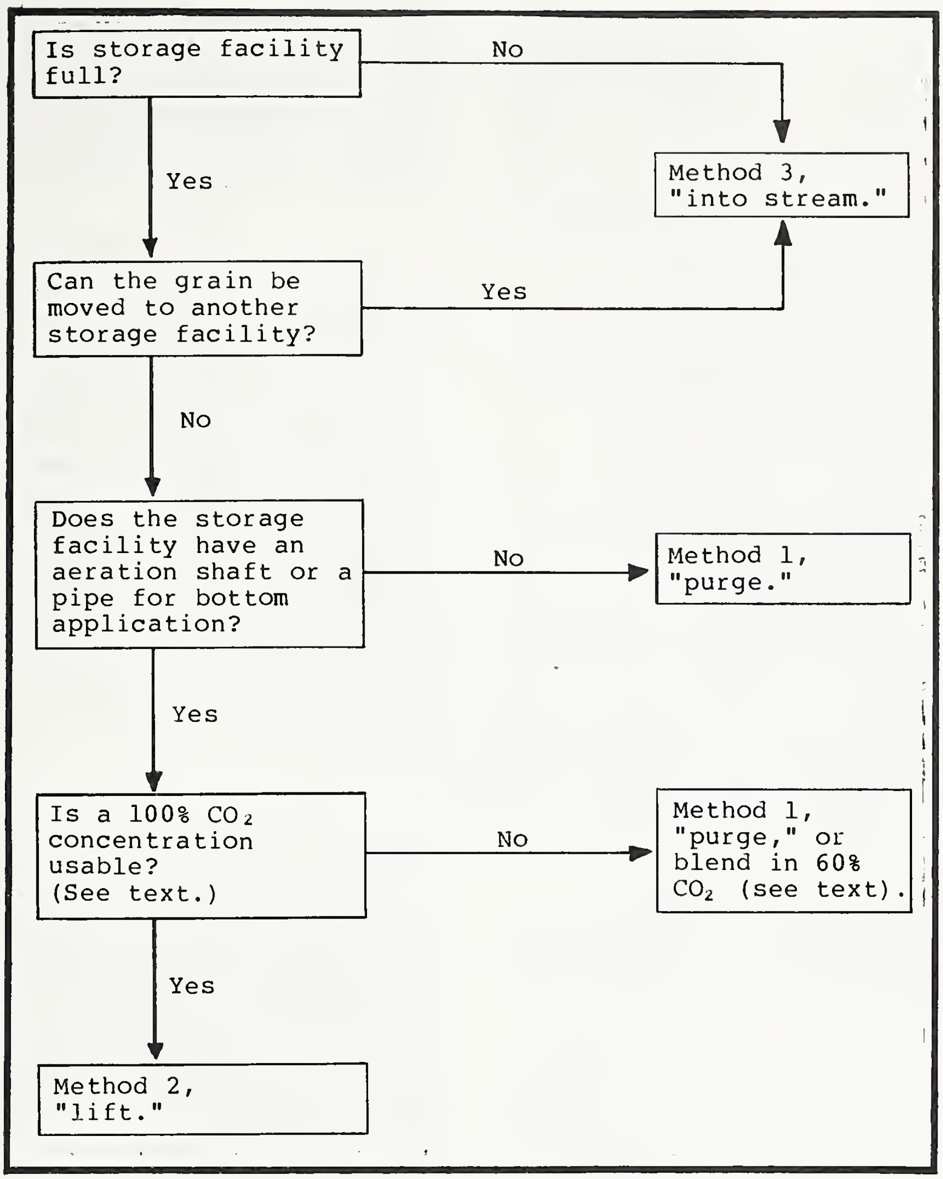

FIGURE 2.—Selecting a method for applying CO_2.

METHOD 3: APPLY CO_2 IN THE GRAIN STREAM

This test was conducted with liquid CO_2 from the same tank previously described. The CO_2 emerged from the equipment in a semisolid form called "snow" by the CO_2 industry. However, the snow soon sublimated and produced CO_2 gas. A CO_2 "horn" was attached to copper tubing (1.9-cm i.d., or ¾-inch), which was run from the liquid line on the CO_2 tank to the top of the silo. The tubing and horn were thoroughly grounded to prevent any sparks around the discharge area. Liquid CO_2 flow was started into an empty silo at the outer access opening, and in 10 min about 49.4 m^3 (200 lb) had been introduced. Corn flow was then started into the silo and continued, with two brief interruptions of 3 min each, until the silo was filled with about 711 metric tons (28,000 bu) of corn in 2.33 h. At this point about 642 m^3 (2,600 lb) of CO_2 had been introduced into the silo at a rate of 4.6 m^3/min (18.6 lb/min). Carbon dioxide application was continued an additional 0.6 h, except for a 10-min interruption. At this time an

Table 1.—Characteristics of three CO_2 application methods

[CO_2 applied to 711 metric tons (28,000 bu) of corn]

Characteristic	Application method		
	Method 1, "purge"	Method 2, "lift"	Method 3, "into stream"
Time to attain lethal concentration (h)	8	16.5	3
Quantity to reach lethal concentration:			
Cubic meters [1]	625	716	827
Pounds	2,530	2,900	3,350
Quantity to maintain lethal concentration for 96 h (including purge time):			
Cubic meters per hour	17.8	[2]19.3	19.3
Pounds per hour	72	[2]78	78
Total CO_2 to treat:			
Cubic meters	2,332	2,568	2,679
Pounds	9,445	10,400	10,850
Cost per bushel ($):			
CO_2 at $0.052/lb [3]	0.0175	0.0193	0.0202
CO_2 at $0.078/lb [4]	0.0263	0.0290	0.0290
CO_2 at $0.090/lb [5]	0.0304	0.034	0.0349
Cost per metric ton ($), CO_2 at $0.052/lb [3]	0.691	0.761	0.794

[1] Calculated from 8.72 ft^3 CO_2 gas produced from 1 lb CO_2 liquid at -17.8° C and 305.5 lb/in^2 absolute.
[2] Calculated from "into stream" application, method 3.
[3] U.S. price, 1978, yearly usage of 100-500 tons CO_2.
[4] U.S. price, 1978, yearly usage of 50-100 tons CO_2.
[5] U.S. price, 1978, yearly usage of 0-50 tons CO_2.

additional 98.8 m^3 (400 lb) of CO_2 had been applied, and a small mound of snow had accumulated directly under the horn on the surface of the corn.

During filling, gas samples were taken adjacent to the access door where the CO_2 was being introduced. These samples were taken when excessive CO_2 blowback from the silo was noticed. Carbon dioxide concentrations were 5.4% to 16.2%, indicating a large loss of gas from the silo.

Three and one-half hours after the start of application (30 min after the snow had accumulated on the top of the corn), a complete series of air samples was taken from this silo. These 12 samples averaged 71% CO_2 and 6% O_2. The concentration of CO_2 ranged from 82% to 24%, and the O_2 concentration ranged from 2.1% to 11.4%.

Two and one-half hours after the application was stopped, an additional 86.4 m^3 (350 lb) of snow was applied through the top of the silo in 20 min. Twenty minutes later, the CO_2 average was 60%, and the O_2 average was 8% in all 12 samples. In this series of samples, the 1-m side sample contained 37% CO_2, and the 25-m center sample contained 44% CO_2; the range of CO_2 was 84% to 37%, and the O_2 range was 4% to 11%.

To maintain the CO_2 concentration, gas was reintroduced 6 h after the initial introduction. This was accomplished by running a 1.9-cm-i.d. (¾-inch) rubber hose from the gasline on the tank into the headspace of this silo. Gas flow was controlled by a CO_2 analyzer equipped with relays that controlled a solenoid valve in the application line. The controller was calibrated to maintain 55% to 60% CO_2 in the silo. This equipment is described in more detail by Jay and Pearman (1973).

Sixteen hours later, a complete series of gas samples was taken from the silo. The CO_2 concentration ranged from 59% to 52%, and the O_2 concentration ranged from 8% to 10%. The test was terminated at this point since experience has shown that once the desired concentration has been attained, the CO_2 analyzer and associated equipment will maintain the concentration within the silo at the concentration lethal to most stored-grain and oilseed insects.

This method is fast, and vaporization equipment requirements are low. The disadvantages in-

clude danger of explosion caused by improperly grounded application equipment, a potential need for two application lines, excessive loss of CO_2 from blowback, and high labor requirements (constant attention during application is required).

DISCUSSION

The decision on which application technique to use will have to be based on several factors (fig. 2). Table 1 presents a breakdown of the CO_2 costs for each method. The costs are based on the quantities of liquid CO_2 used in each test at the most recent prices the author could obtain and do not include the expense of renting storage tanks and vaporization equipment. At the lowest quoted price for CO_2, the costs ranged from $0.0175/bu ($490 for 28,000 bu) for method 1 to $0.0202/bu ($565 for 28,000 bu) for method 3. Since each method has its advantages and disadvantages and, in some cases, only one or two of the three methods could be used, the difference in cost between the three methods may be considered minimal.

These studies were conducted at only one storage facility, in upright concrete silos containing corn. Little effort was made to correct the obviously high leakage. Anyone using this information to conduct further field tests should consider all potential leaks. In upright concrete silos any cracks in walls are potential areas for gas leaks. The largest losses will occur around the discharge spouts at the bottom of the silos.

Each facility to be treated with modified atmospheres will have varying factors of volume, type and amount of grain, leak rate, temperature, vaporization equipment (if required), and other factors. Therefore, this information should be used as a guide and not as a representative indicator as to how a treatment will work in a given situation. Additional field studies are needed.

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